CSS File

UDC 621.391.812.63

1969
THE QUEEN'S AWARD
TO INDUSTRY

RESEARCH DEPARTMENT

REPORT

A simulator of ionospheric propagation of amplitude modulated signals

No. 1969/24

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

A SIMULATOR OF IONOSPHERIC PROPAGATION OF AMPLITUDE MODULATED SIGNALS

Research Department Report No. **1969/24**
UDC 621.391.812.63

It uses SI units in accordance with B.S. document PD 5686.

Work covered by this report was undertaken by the BBC Research Department for the BBC and the ITA

D. Maurice

R.J. Packer
J.A.S. Fox, B.Sc.(Eng.)

Head of Research Department

(RA-42)

Research Department Report No. 1969/24

A SIMULATOR OF IONOSPHERIC PROPAGATION OF AMPLITUDE MODULATED SIGNALS

August 1969

Research Department Report No. **1969/24**
UDC 621.391.812.63

A SIMULATOR OF IONOSPHERIC PROPAGATION OF AMPLITUDE MODULATED SIGNALS

SUMMARY

Broadcast reception over long distances on medium and high frequencies is invariably subject to impairment in quality due to fading and noise interference effects.

The instrument described in this report simulates the fading and multipath effects present in natural ionospheric propagation. Double-sideband modulation over a frequency range between 30 Hz and 12 kHz is used and a modification is described for operation with special types of modulation, e.g. single sideband. Gaussian noise can be introduced into the fading signal to represent signal-to-noise ratios experienced when receiving broadcasts under adverse conditions.

Details are given of the main design considerations together with measured performance data. The instrument has proved valuable as a laboratory facility for evaluating various systems designed to raise the quality or intelligibility of the received signal.

1. INTRODUCTION

An appraisal of a broadcasting service must take into account distortion of the received signal arising from propagation effects; the distortion may be dependent on the system of modulation and on the form of modulation signal processing used at the transmitter. Investigations of these effects, in the case of m.f. or h.f. services involving ionospheric propagation, are difficult to carry out in the field and require considerable time. The work can be shortened if propagation effects, including fading, can be reproduced in the laboratory under controlled conditions. The simulator to be described was designed to provide this facility.

The short-term amplitude of a fading signal in the h.f. band, even when only a single reflection from the ionosphere is involved, has been found to approximate closely to a Rayleigh distribution.[1,2] This is consistent with the theory that the received signal is the resultant of a number of signals randomly varying in phase and amplitude produced by the non-uniform structure and movements of the ionosphere. Frequency-selective fading results from appreciable differences in propagation times (up to about 2 ms) along two or more different paths,[3] e.g. with single and multiple reflections from a single layer, with reflections from different layers, or, at medium frequency, with ground and sky waves. The received signal-to-noise ratio is, in practice, dependent on various factors, but the range of practical interest lies between zero and 50 dB. The simulator is therefore required to reproduce such fading effects and signal-to-noise ratios.

The basic design largely follows that of the fading simulator developed by H.B. Law at the Post Office Research Station[4] which provided two complete systems to permit investigation of spaced-aerial diversity reception. Each system generated a resultant radio signal from six crystal oscillators drifting independently around a nominal carrier frequency of 100 kHz, and therefore in a slowly-varying random phase relation to one another.

The essential principle of this equipment, which was retained in the BBC design, was that a modulated r.f. signal which traverses two paths whose time delays are large but varying slowly is simulated by two separate oscillators and modulators, a fixed time delay being inserted in the a.f. feed to one of the modulators. The use of separate oscillators simulates the phase change caused by the slow variation of the delay in the ionosphere. By extension, a group of oscillators and modulators may replace a single oscillator in order to obtain the random amplitude of a signal traversing a single path in the ionosphere.

The Research Department design differs from that of the Post Office in a number of respects because the requirements of broadcasting differ from those of wireless telegraphy and telephony; e.g. a greater modulation bandwidth is employed. Opportunity was taken to simplify the apparatus where possible and this, together with the use of semiconductors, enabled a considerable reduction in size to be made. The applications were primarily concerned with domestic receivers using simple aerials and, for this reason, only single-aerial working was simulated. Provision

was made, as in the Post Office simulator, for adding noise to the fading signal for controlled impairment experiments.

2. GENERAL ARRANGEMENT

A block schematic diagram of the equipment is shown in Fig. 1. The apparatus is designed to accept programme input levels of 0 dBm, corresponding to 40% modulation of each carrier.

The distribution amplifiers couple the audio output from the peak clipper to the modulators by two paths, one direct and one which passes through the delay line. Each path supplies a group of three of the six modulators, so that the signals in one group are delayed by up to 2 milliseconds. The modulators, each of which can be adjusted for modulation depth and balance, obtain their carrier signals from independent crystal oscillators. Each carrier frequency may be finely adjusted over a few hertz. The output from each modulator passes via a buffer amplifier to a 'star' summing amplifier circuit; this arrangement isolates the oscillators from each other, thus preventing 'pulling' and locking of the carriers. R.F. Gaussian noise, which can be adjusted in level over a range of 60 dB by a built-in attenuator, is introduced at this point in the circuit. A bandpass filter removes carrier harmonics and unwanted modulation products, the fading signal being finally converted in the balanced r.f. modulator to a signal in the range between 0·5 MHz and 30 MHz. An audio signal for comparison and setting-up purposes is obtained by demodulating the fading signal with an envelope detector, filtering out the high frequency components and providing an output of the demodulated audio signal at normal level.

The stability of the oscillators, and hence of the fading rate, is improved by passing warm air through the cabinet. A thermal bridge controls the air heaters so that the temperature of the oscillator section is maintained within a range of 35 ± 0·5°C.

A general view of the equipment is shown in Fig. 2. Research Department 'Minar' assemblies are used throughout, the sections being contained in five standard 19 in. frames. Each unit can be removed for servicing and all adjustments may be made from the front.

3. OSCILLATOR AND MODULATOR UNITS

The circuit diagram of an oscillator and modulator unit is shown in Fig. 3. Each oscillator employs a +5° X-cut quartz crystal and is adjustable over a frequency range of 10 Hz by a trimmer capacitor. Random fading results from each oscillator drifting slowly in frequency with respect to the others. Cyclic fading is avoided by using the differences in temperature coefficients of nominally identical crystals, so that those with large coefficients are offset in frequency furthest from the mean frequency of all the carriers, and those with smaller coefficients closer to the mean frequency. Recordings of the fading carrier signal were made using a pen recorder over long periods in order to check that no cyclic fading was occurring.

Modulation of the 100 kHz carrier is carried out by a 'ring' type balanced modulator; d.c. bias is applied to the ring so that the output carrier level is 50% of its peak value in the absence of audio modulation. In this arrangement, if the peaks of the audio modulating voltage were to exceed the d.c. bias, the modulator would produce phase-reversed carrier and sideband components since it is basically a suppressed carrier modulator. The peak clipper restricts the modulation signal, however, so that the 100% point is not exceeded.

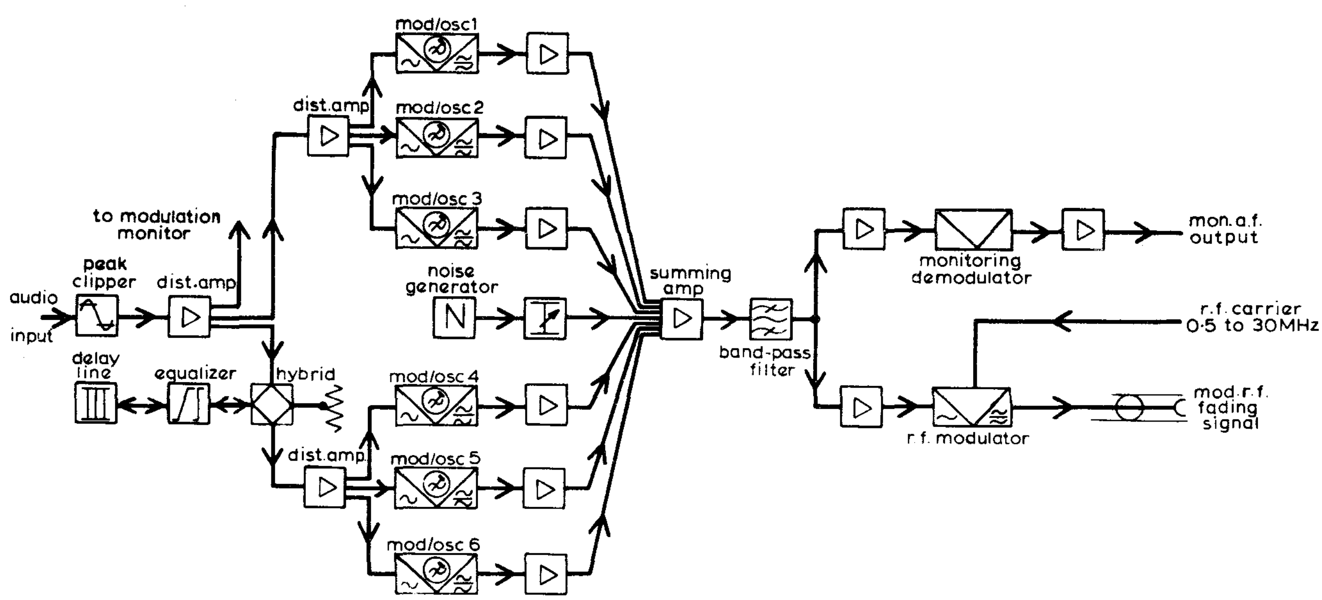

Fig. 1 - Block schematic diagram

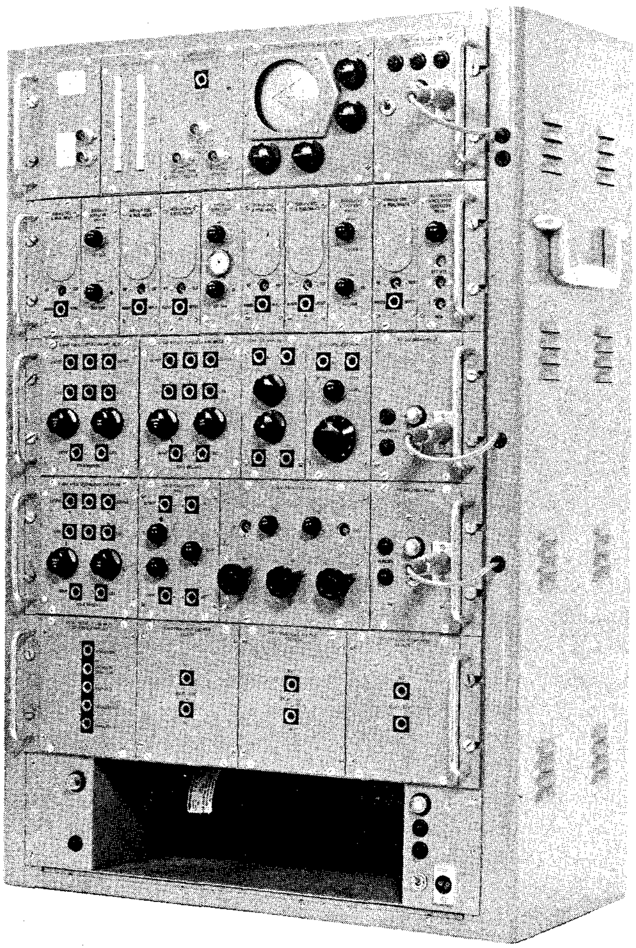

Fig. 2 - General view of the equipment

4. NOISE GENERATOR

An alternative to the saturated diode or gas discharge method of generating random electrical noise has been found in the use of a semi-conductor voltage-reference diode as a noise source. Zener and avalanche diodes are both frequently classified as zener diodes, but it is the avalanche type that generates noise when the diode is in its voltage-reference mode of conduction. It has been reported elsewhere[5,6] that a noise voltage is generated by an avalanche diode operating in its breakdown region, when the diode current may be between 30 μA and 150 μA. The parameters controlling the amplitude and spectral distribution of the noise have been determined[5] and noise diodes have been manufactured from the data obtained.

In the circuit of the 100 kHz noise generator, use was made of the noise voltage generated by an avalanche diode when operating in the centre of one of the narrow current 'shelves' in the diode characteristic which have been found to occur for currents generally between 1 mA and 15 mA. The shelves are up to 100 μA wide and in this range the slope resistance tends to zero. Fig. 4 illustrates the variation in the noise voltage generated with a diode over a small range of its current/voltage characteristic. In the 'shelf' mode of operation, the diode can be loaded with quite low impedances. By selection and adjustment of the current, up to 1 mV of r.m.s. noise voltage in a 100 kHz band can become available at the diode terminals.

The spectral noise distribution is uniform up to several hundred kilohertz and, although non-uniform at higher frequencies, extends into the gigahertz region. The stability of the noise source depends almost entirely on the junction current which, by the use of simple circuits, can be stabilized so that the output voltage remains constant over long periods.

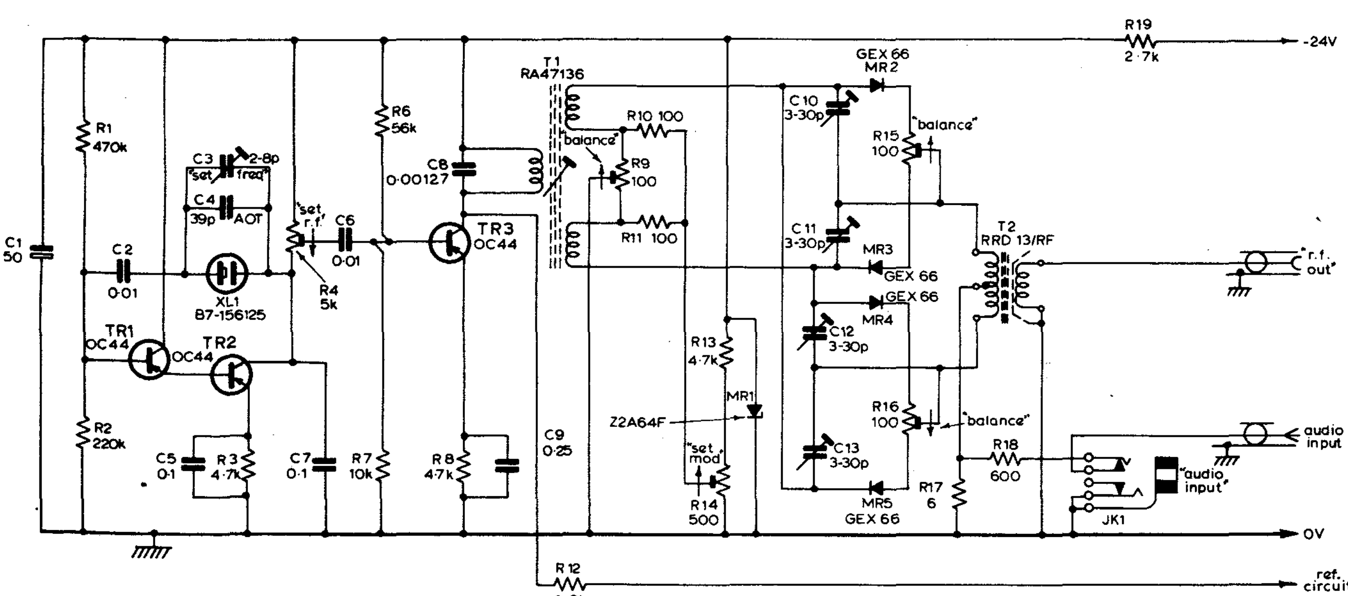

Fig. 3 - Oscillator and modulator: circuit diagram

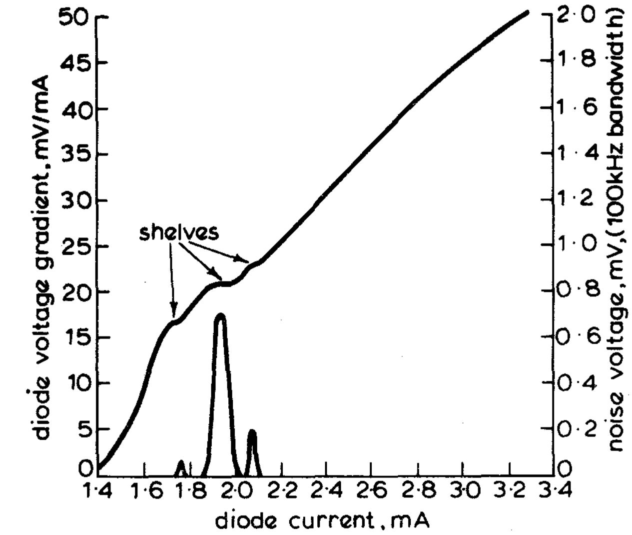

Fig. 4 - Diode noise voltage variation and 'shelf' mode characteristics

The circuit of the noise generator used in the fading simulator is shown in Fig. 5. The filter immediately following the noise diode MR 1 limits the band of noise at the output to frequencies between 90 kHz and 110 kHz (3 dB loss points).

5. DELAY LINE

The design of the delay line was that used in a unit originally developed for general laboratory work.* It employs all-pass bridged-T networks requiring high-Q resonant circuits. Each of the 24 sections introduces 41·7 μs delay over a bandwidth of 10 kHz.

* The basic design of the delay line is due to D.J. Whythe.

The overall group delay is well maintained at 1 ms over the band and the line requires only 1 dB of amplitude equalization at 10 kHz. The effective delay can be doubled by open circuiting the line and using a hybrid transformer as shown in Fig. 1 to separate the direct and reflected signals in the line.

6. FREQUENCY COMPARATOR AND MODULATION MONITORING UNIT

The unit provides check facilities for the carrier level, frequency and modulation depth of each oscillator and modulator unit. It can also be made to display the combined output representing the modulated fading signal. The circuit diagram of the unit is shown in Fig. 6.

6.1. Oscillator Frequency Differences

As already mentioned in Section 3, the oscillators are offset from a mean frequency so as to reduce cyclic fading to a minimum. The offset can be observed as a rotating arc on the built-in oscilloscope, so that one revolution per second indicates an offset of one hertz. The display is achieved by using a circular time-base derived from one of the six oscillators (taken as the reference-frequency oscillator) and by brightening the trace over an arc of about 120 degrees with a pulse derived from the oscillator under test. Thus, with the aid of a stop-watch, it is possible to observe accurately the difference frequency between any of the five remaining oscillators and the reference oscillator. The sign of the frequency difference is readily observed from the sense of rotation.

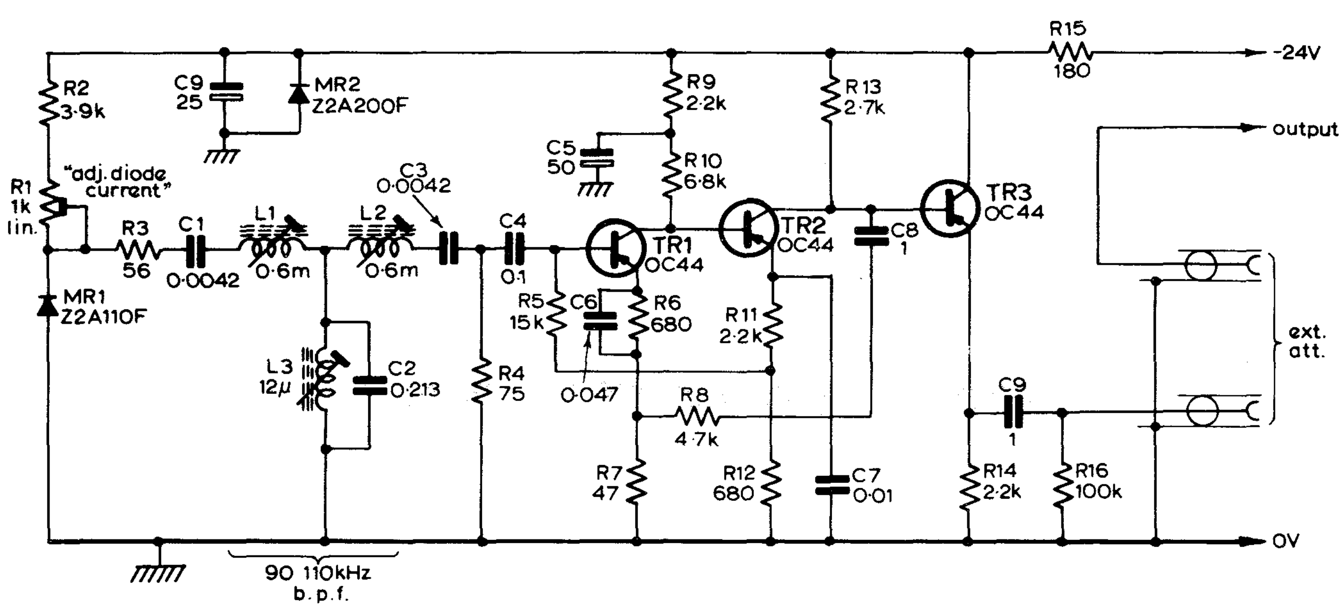

Fig. 5 - 90 – 110 kHz noise generator: circuit diagram

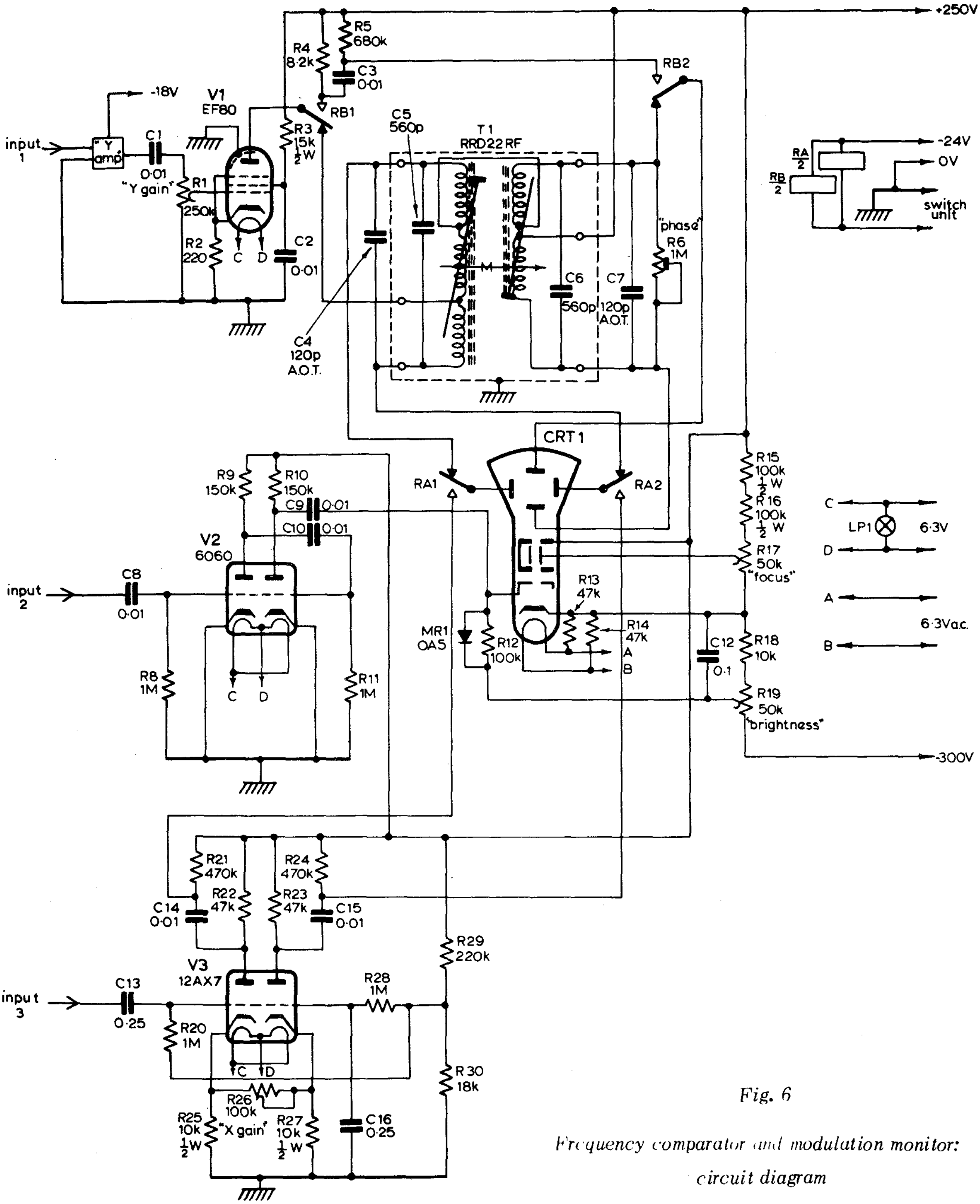

Fig. 6

Frequency comparator and modulation monitor: circuit diagram

6.2. Modulation Monitoring

The conventional 'trapezium' display is produced on the oscilloscope by applying to the 'X' input a signal from an audio-frequency oscillator, which also modulates the carrier under test, and to the 'Y' input the modulated 100 kHz signal. By appropriate switching it is possible to check the carrier amplitude and depth of modulation of each modulator in turn. A triangular graticule is provided to facilitate these operations.

7. PERFORMANCE

The amplitude distribution of the fading signal was measured by mixing the r.f. fading signal with a larger c.w. signal differing in frequency by about 1000 Hz and passing the output of a linear detector to a statistical level analyser.[7] This was carried out over a period of one hour for a quasi-fading-rate of 5 fades per minute. The result is shown in Fig. 7 together with an ideal Rayleigh distribution for comparison. It will be noticed that, over a large range of the levels, the approximation is quite good. Quasi-fading-rates down to 0·25 fades/minute are obtainable over long periods and the maximum rate is in the region of 400 fades/minute.

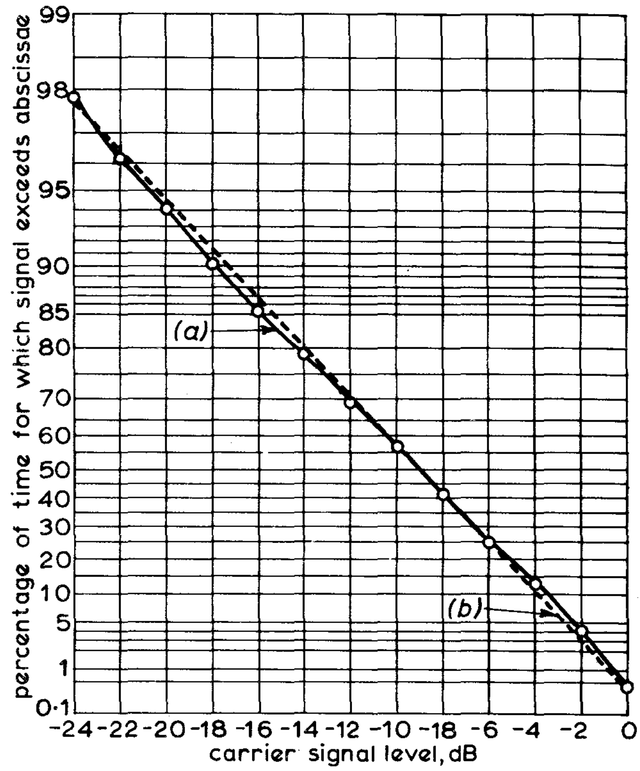

Fig. 7 - Amplitude distribution of fading signal
(a) measured distribution (b) ideal Rayleigh distribution

The distortion of any one modulator is kept well below a weighted distortion figure (measured at 1 kHz for 10 harmonic terms) suggested as acceptable for a wide range system by E.R. Wigan.[8] The signal-to-noise ratio at the output, in the absence of added noise from the generator, is 54 dB (reference 100% modulation) for one modulator. The mean value of signal-to-noise ratio for a fading signal output would exceed this value.

The warm-up period required for stabilizing the temperature depends on the ambient temperature and lies typically between one and two hours. A small dial thermometer located on the front panel indicates when the working temperature has been reached.

8. FURTHER DEVELOPMENTS

During construction of the fading simulator described above, the need arose to simulate fading of a compatible single-sideband (c.s.s.b.) signal under typical conditions of either medium frequency or high-frequency broadcasting. In this system the modulation envelope is similar to that of normal amplitude modulation but the bandwidth approaches that of a single sideband system. It is generated by a combination of amplitude and phase modulation[9,10] and the use of a complex modulator for each of the six channels of the fading simulator was considered impractical.

A second version of the fading simulator was therefore constructed using a slightly different principle. A block schematic diagram of this is shown in Fig. 8 for the case in which long-distance h.f. propagation is simulated. The amplitude-modulated crystal oscillator units are replaced by crystal oscillators (at 100 kHz nominal frequency) followed by mixers which are fed with modulated r.f. signals from a single c.s.s.b. modulator. The purpose of each mixer is to act as a frequency-changer of random phase shift, an output being available at a frequency 100 kHz above (or below) the r.f. input frequency.

A single c.s.s.b. modulator is employed with a carrier frequency of 850 kHz. The output is fed to a commercially available magnetostrictive delay line giving up to 2 ms delay over a bandwidth of 1 MHz. Taps are provided at 0·5 ms intervals along this line, so that a signal with a suitable delay could be fed to three of the group of six crystal oscillator/mixers, the other three being fed from the undelayed 850 kHz modulated signal. The combined outputs of all six units are then passed directly to a receiver; no filters are needed as, using the medium-frequency band, the receiver selectivity adequately separates the 950 kHz signal from the unwanted 850 kHz and 750 kHz signals. This arrangement may be readily used for any form of modulation since it only requires a single modulated signal to be provided at the input.

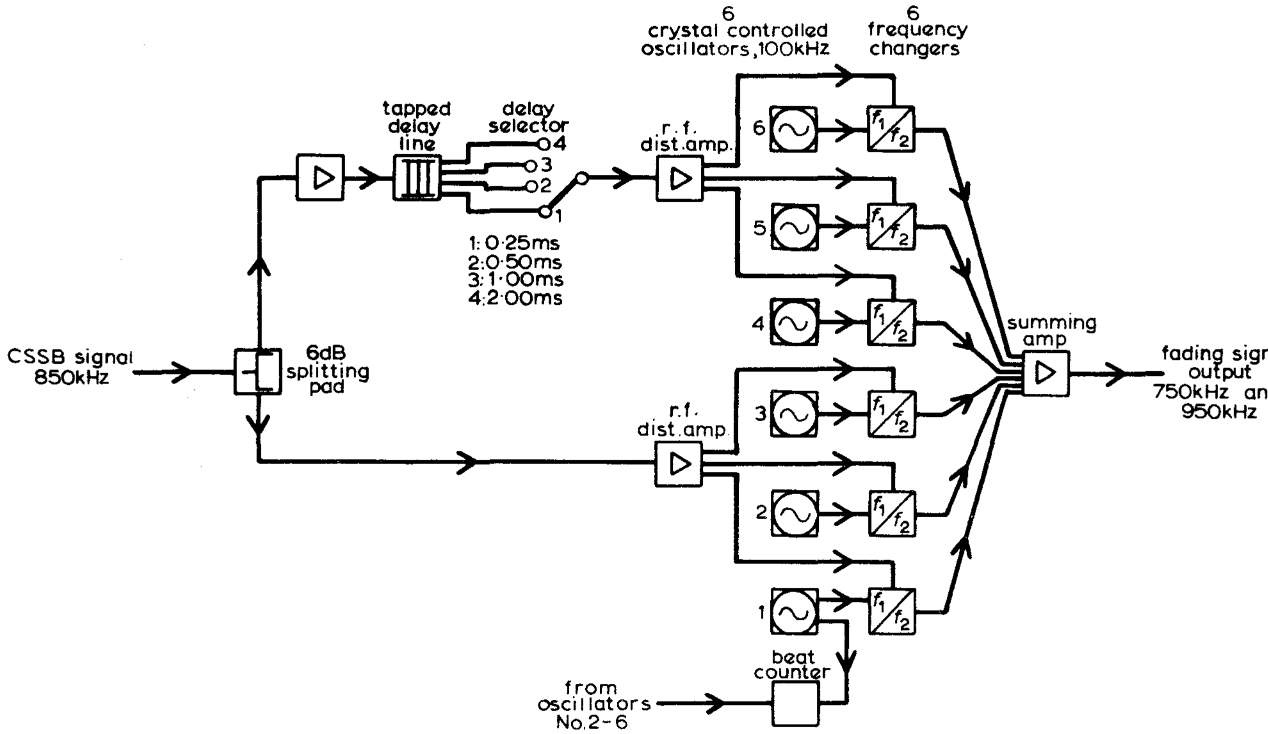

Fig. 8 - Block schematic diagram: c.s.s.b. arrangement

9. CONCLUSIONS

The signal produced by the six modulated carrier components, with the use of a delayed modulation signal for some of them, gives a good approximation to the fading effects found in practice with radio signals transmitted in the h.f. band over long distances via the ionosphere. No attempt has been made to introduce into the signal man-made or atmospheric noise, though, by the addition of Gaussian noise, it is possible to closely reproduce under controlled conditions the type of deterioration which occurs in h.f. broadcasting and reception over long distances.

The equipment has been used successfully in general subjective appraisals of various modulation input processing systems for transmitters and, in the modified form, to assess an alternative to the usual double sideband modulation in general use for a.m. transmissions.[10] Besides simulation of h.f. paths, either form of simulator can be used to simulate ground-wave plus sky-wave propagation at medium frequency by the use of a single oscillator unit in the direct path.

Commercial interest has been shown in the novel use of avalanche diodes as generators of random noise at r.f. and an effort is being made to establish the controlling parameters in manufacture.[11]

10. REFERENCES

1. RATCLIFFE, J.A. Diffraction from the ionosphere and the fading of radio waves. *Nature*, 1948, **162**, p. 4105.

2. McNICOL, R.W.E. The fading of radio waves at medium and high frequencies. *Proc. Inst. elect. Engrs.*, November 1949, **96**, III, 44, pp. 517–524.

3. KIFT, F. The propagation of high-frequency radio waves to long distances. *Proc. Inst. elect. Engrs.*, March 1960, **107B**, 32, pp. 127–140, (Paper 3156 E).

4. LAW, H.B., LEE, F.J., LOOSER, R.C., *and* LEVETT, F.A.W. An improved fading machine. *Proc. Inst. elect. Engrs.*, March 1957, **104B**, 14, pp. 117–123 (Paper 2150 R).

5. HAITY, R.H. Controlled noise generation with avalanche diodes. *IEEE Transactions*, April 1965. Electronic Devices, **ED 13**, 3, pp. 342–346.

6. EDWARDS, L. White noise: its nature, generation and applications, *Electronics World*, November 1962, p. 40.

7. New equipment for the statistical analysis of sound programme levels. Research Department Report No. L-070, Serial No. 1966/65.

8. WIGAN, E.R. New distortion criteria. *Electronic Technology,* April 1961, **38**, 4, pp. 128–137; May 1961, **38**, 5, pp. 163–174.

9. VAN KESSEL, T.J., STUMPENS, F.L.U., *and* UYEN, J.M.A. A method for obtaining compatible single-sideband modulation. *E.B.U. Rev.*, 1962, 71A, pp. 12–19.

10. Compatible single-sideband modulation: Experimental investigation of the performance with conventional a.m. receivers. Research Department Report No. G–100, Serial No. 1966/15.

11. HAITZ, R.H. Controlled noise generation with avalanche diodes: I, low pulse rate design. April 1965, *IEEE Trans.*, **ED 13**, No. 3, pp. 342–346.

JMP

Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey